2012

The Right Answer for the Right Reason

Jerad Bales
USGS, USA

USGS
science for a changing world

The Right Answer for the Right Reason

(Kirchner, 2006)

50 Years of Watershed Modeling
24 – 26 September 2012
Boulder, CO

Dr. Jerad Bales
U.S. Geological Survey
Chief Scientist for Water

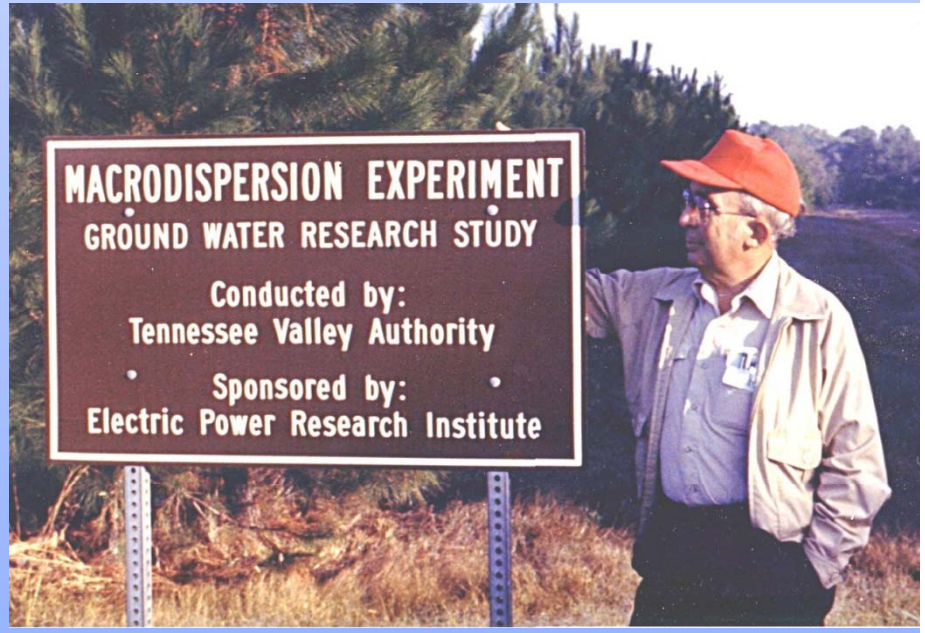


Photo credit: Lynn Starnes

What is Watershed Runoff?

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 69, NO. 8 APRIL 15, 1964

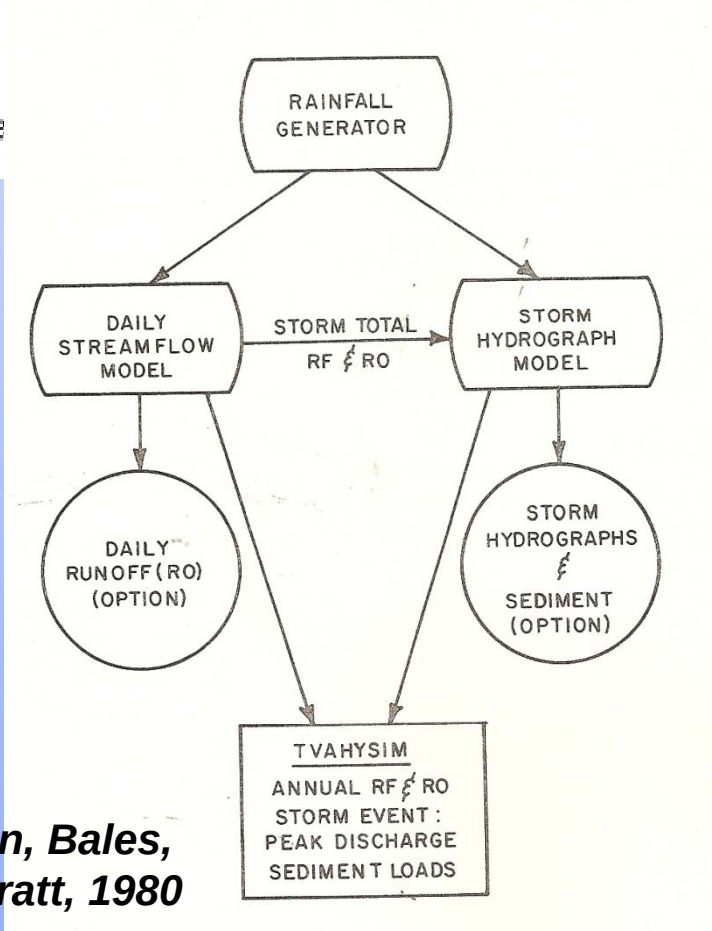
What Is Watershed Runoff?

ROGER P. BETSON

Tennessee Valley Authority, Knoxville

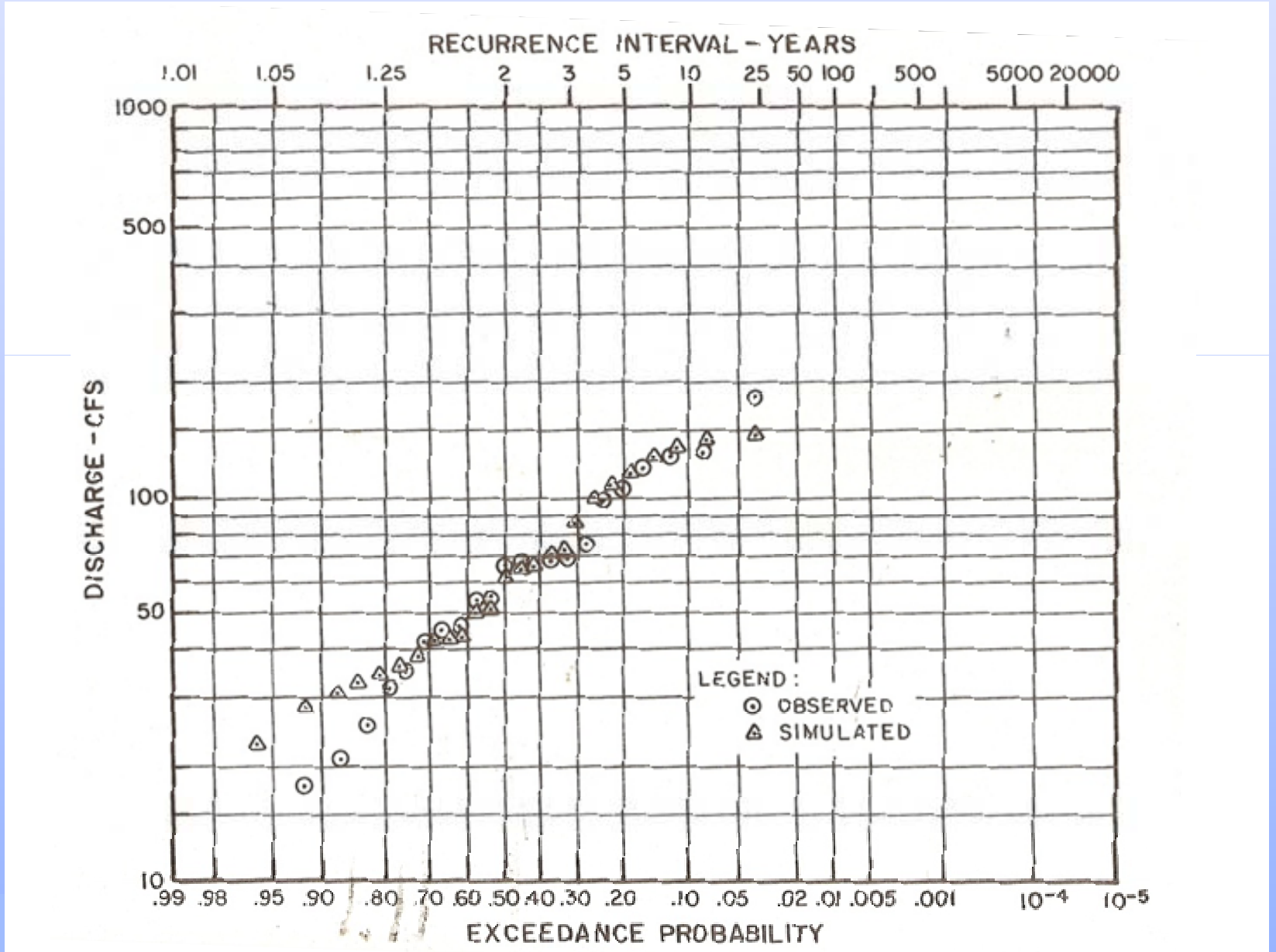
Roger and Margaret, 2002

Photo credit: Lynn Starnes



Betson, Bales, and Pratt, 1980

Are We Doing Better Than in 1986?



Betson, Bales, and Deane, 1981

Yes . . .

- **Understanding**
  - Hyporheic zone and GW-SW coupling
  - Transit times of water
  - Heterogeneity and “hot spots”
  - Terrestrial – Atmospheric feedbacks
  - Co-evolution of physical and ecological systems
  - Instrumentation
  - Data accessibility
- **Modeling**
  - Agri-ecosystems (DRAINMOD, SWAT)
  - Hyporheic zone (OTIS)
  - Coupled GW – SW modeling (GSFlow)
  - Loose coupling to climate models
  - Uncertainty
  - Large modeling systems

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Watershed Modeling for . . .

- **Scientific Understanding**

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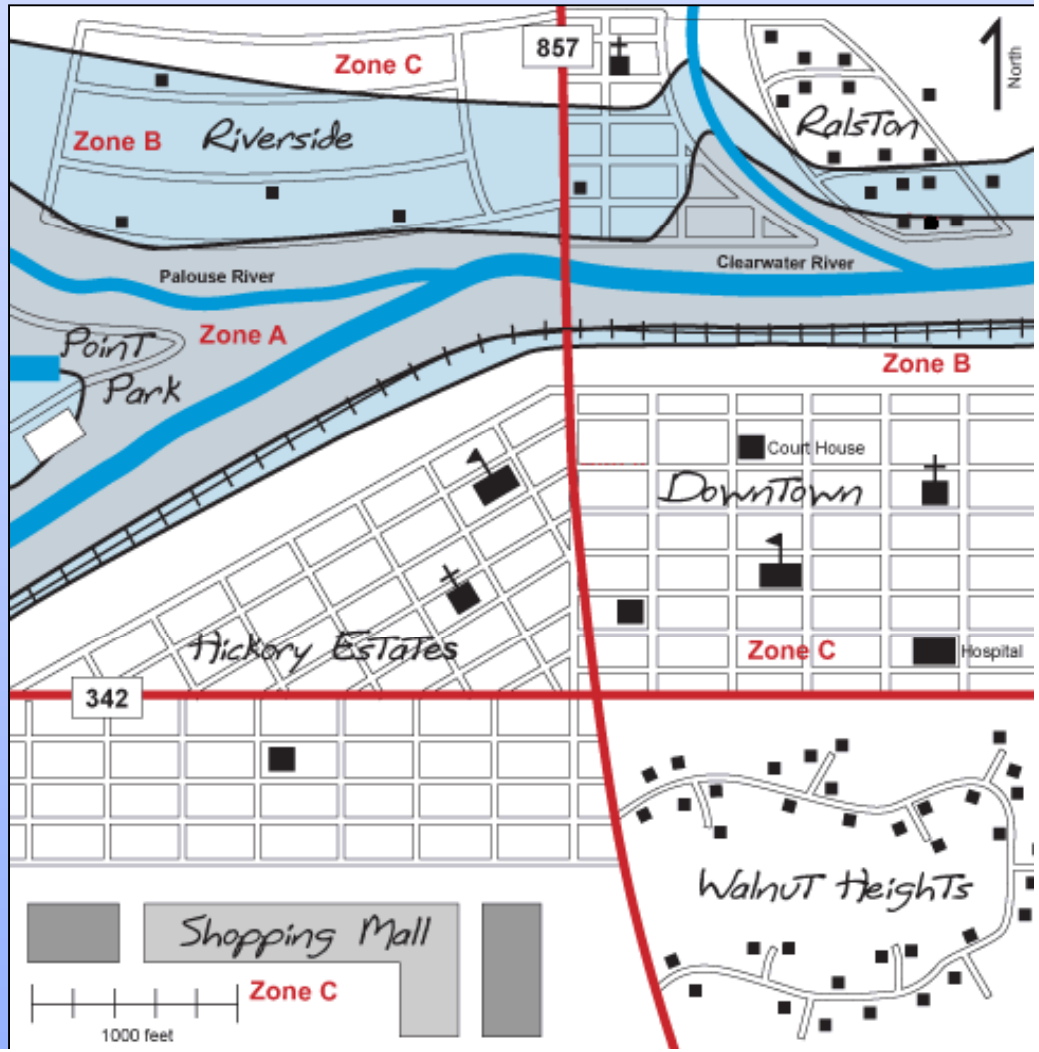
Watershed Modeling for . . .

- **Scientific Understanding**
- **Engineering Design**



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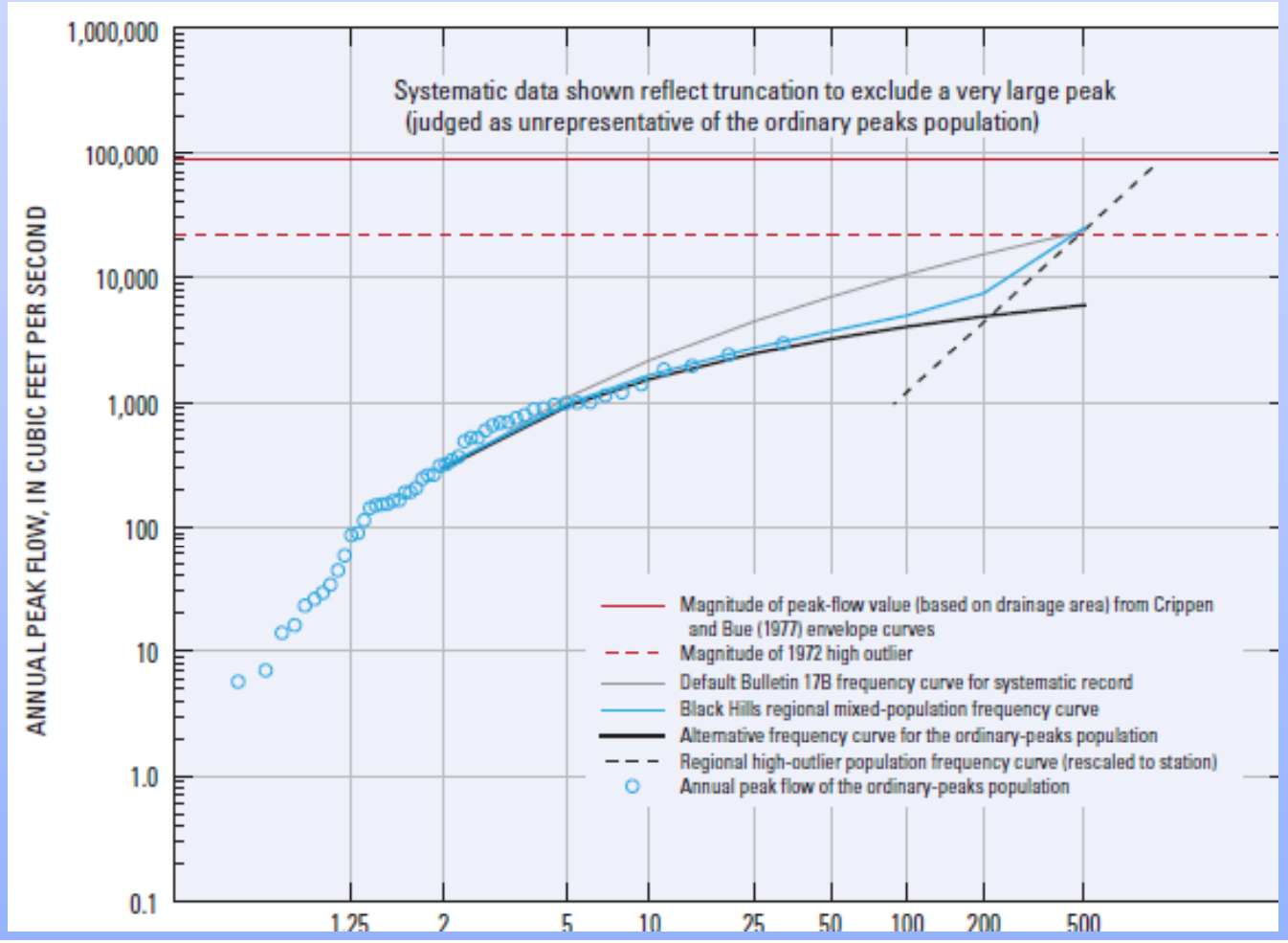
Watershed Modeling for . . .

- **Scientific Understanding**
- **Engineering Design**
- **Hazards**



Battle Creek at Hermosa, SD
(Driscoll et al., 2011)

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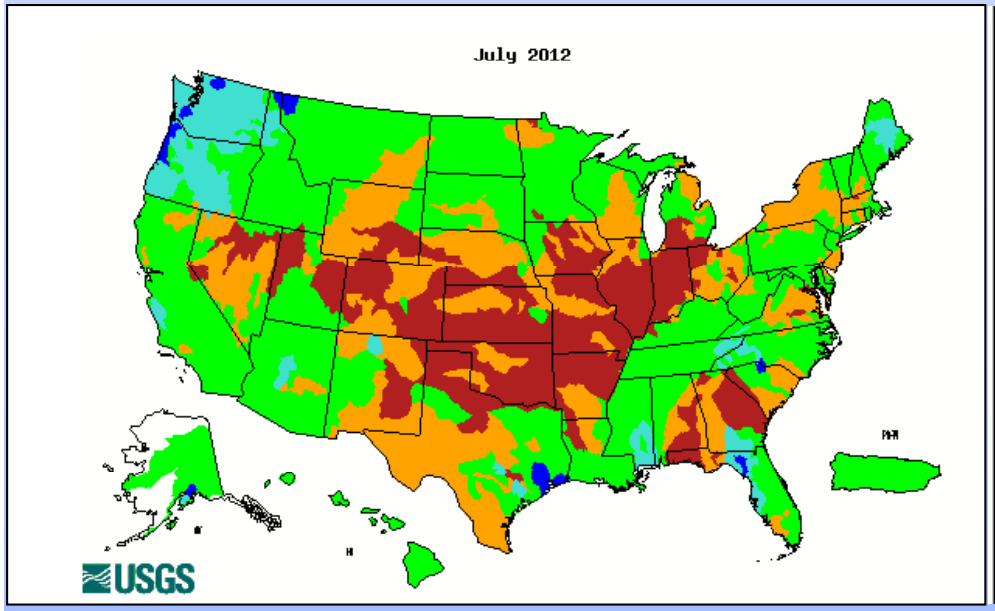
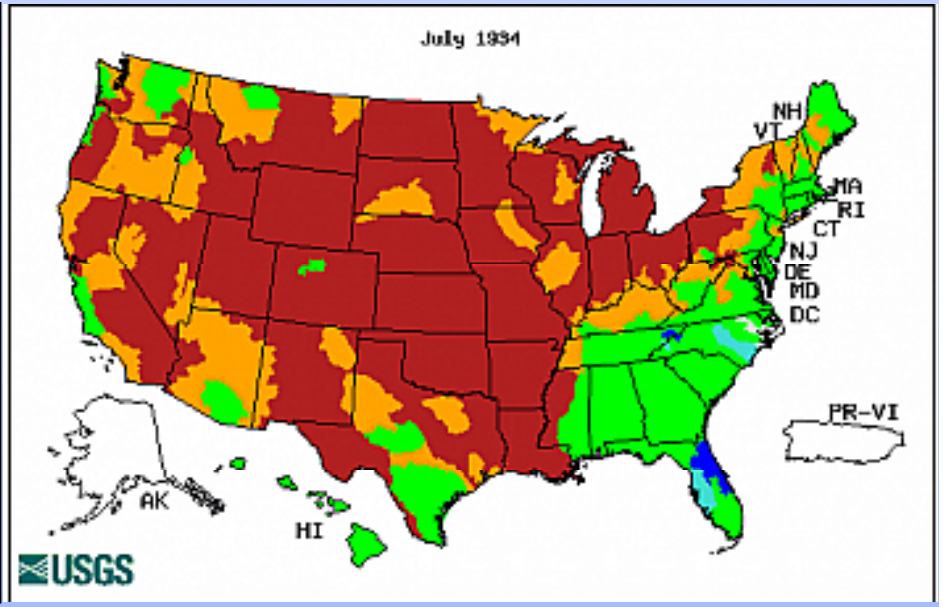
Watershed Modeling for . . .

- **Scientific Understanding**
- **Engineering Design**
- **Hazards**



July 2012



July 1934

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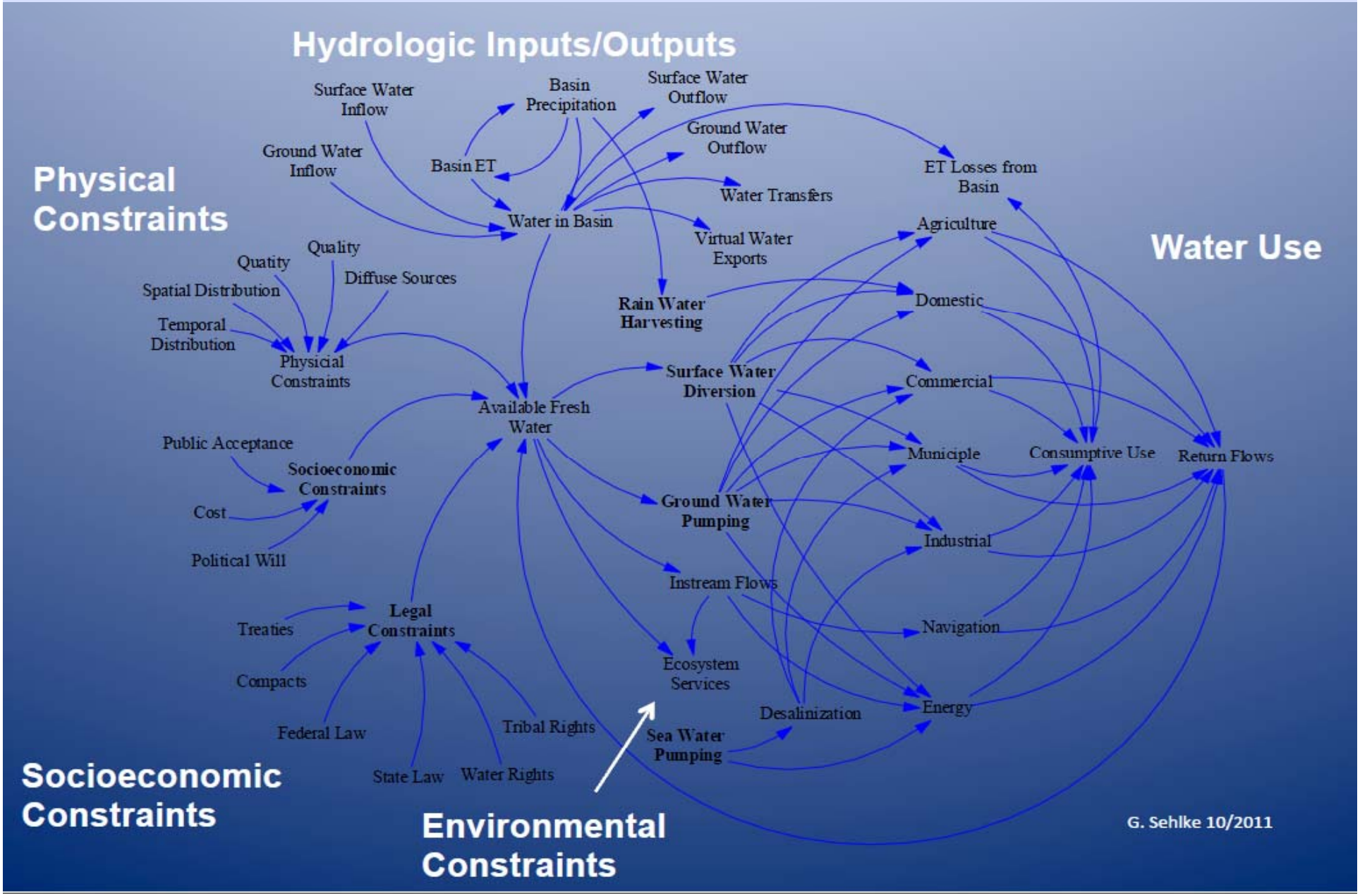
Watershed Modeling for . . .

- **Scientific Understanding**
- **Engineering Design**
- **Hazards**
- **Water-Resources Planning and Management**
  - **Human supply**
  - **Agriculture**
  - **Energy**
  - **Ecosystem needs**

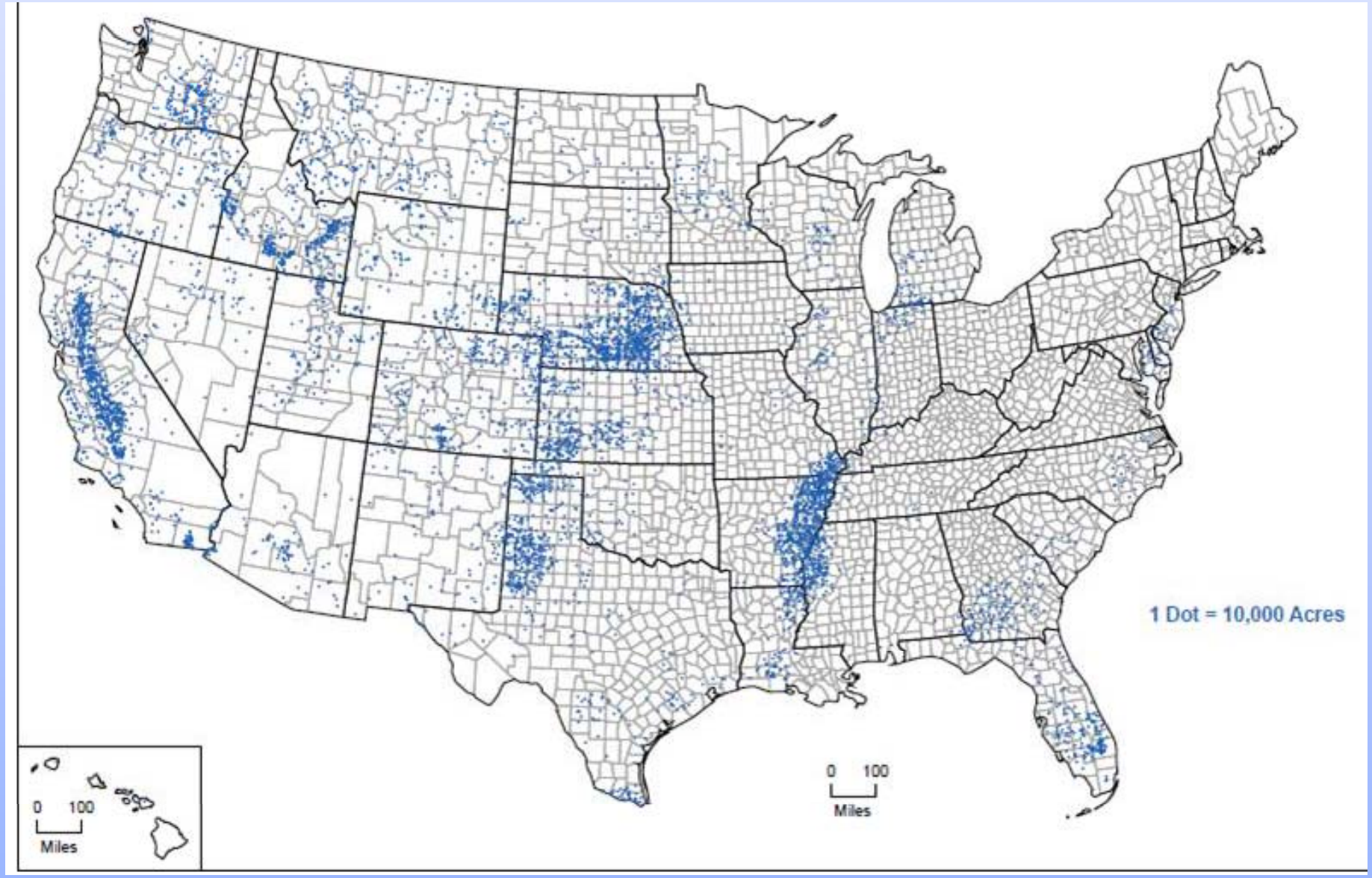
A changing climate

USGS

Natural and Engineered Water Cycle



Irrigated Agriculture



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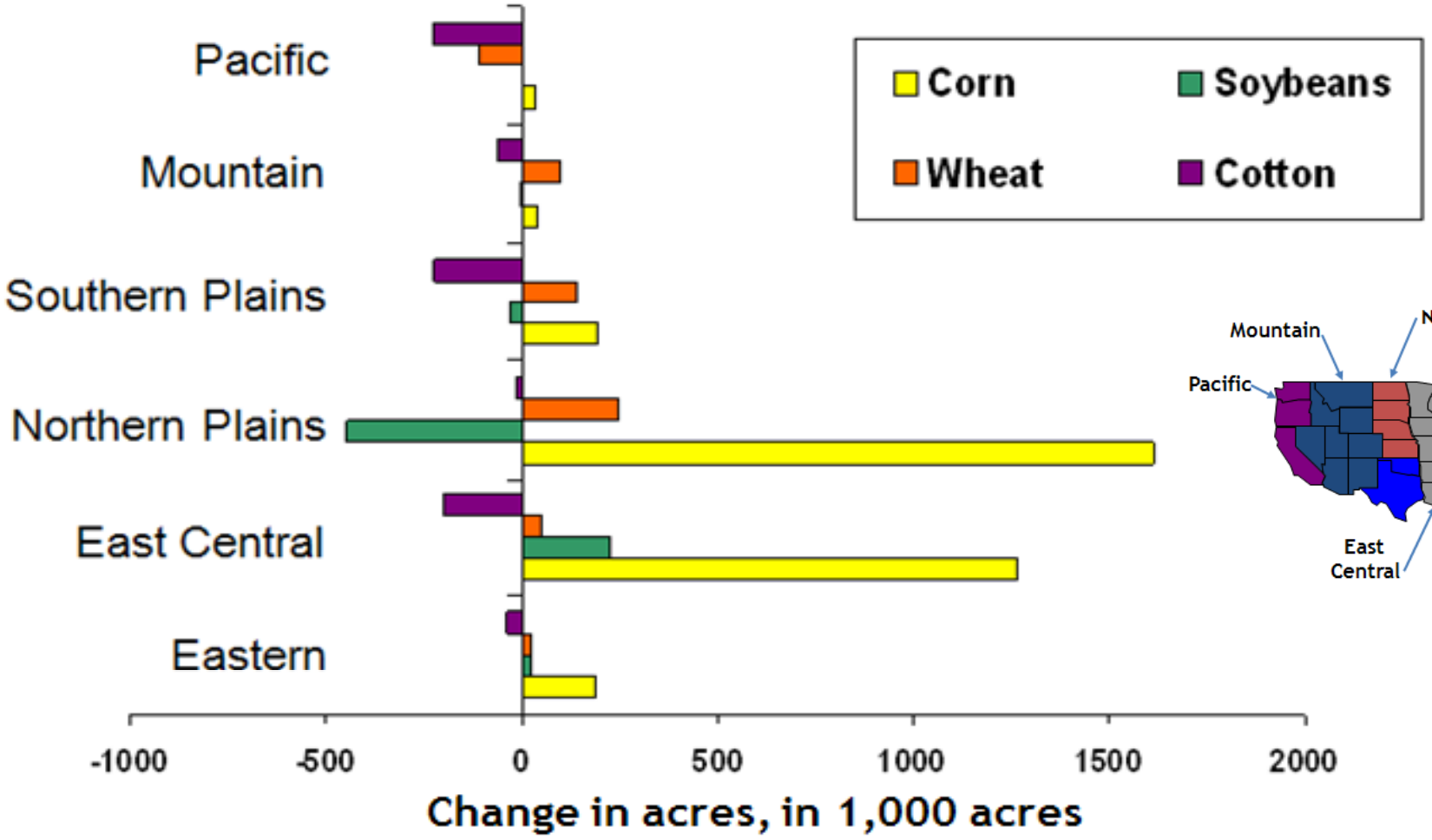
2008 Farm and Ranch Irrigation Survey,
National Agricultural Statistics Service, 2010

Change in Cropland 2002 – 2007

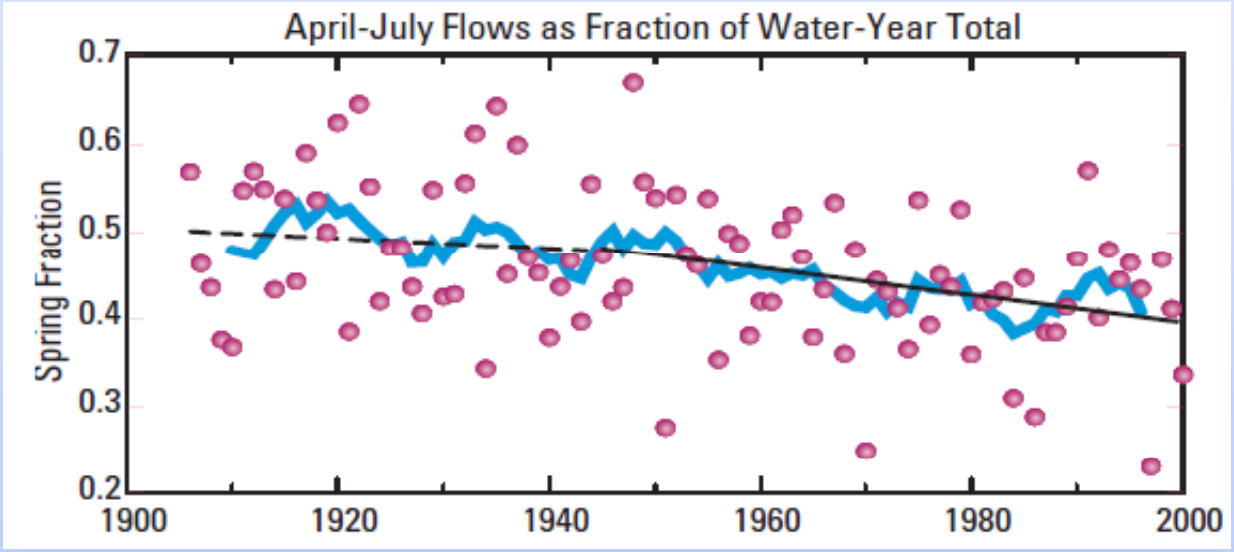


USGS

2008 Farm and Ranch Irrigation Survey, National Agricultural Statistics Service, 2010

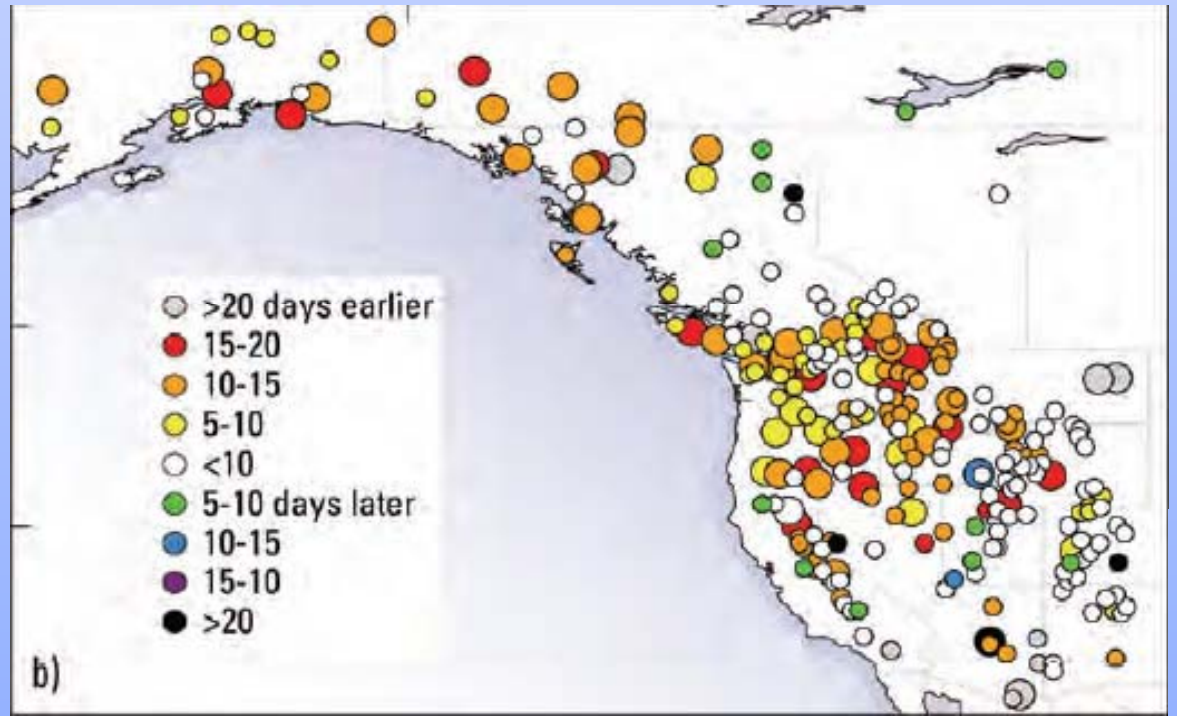
Temporal Redistribution of Streamflow

April – July flow as a fraction of annual flow for 9 western Sierra Nevada rivers. Blue line is 9-yr moving average.



As much as 75% of western water supplies are derived from snowmelt runoff

Trends in center mass of yearly streamflow, 1945 – 2000 (*Dettinger, 2005.*)



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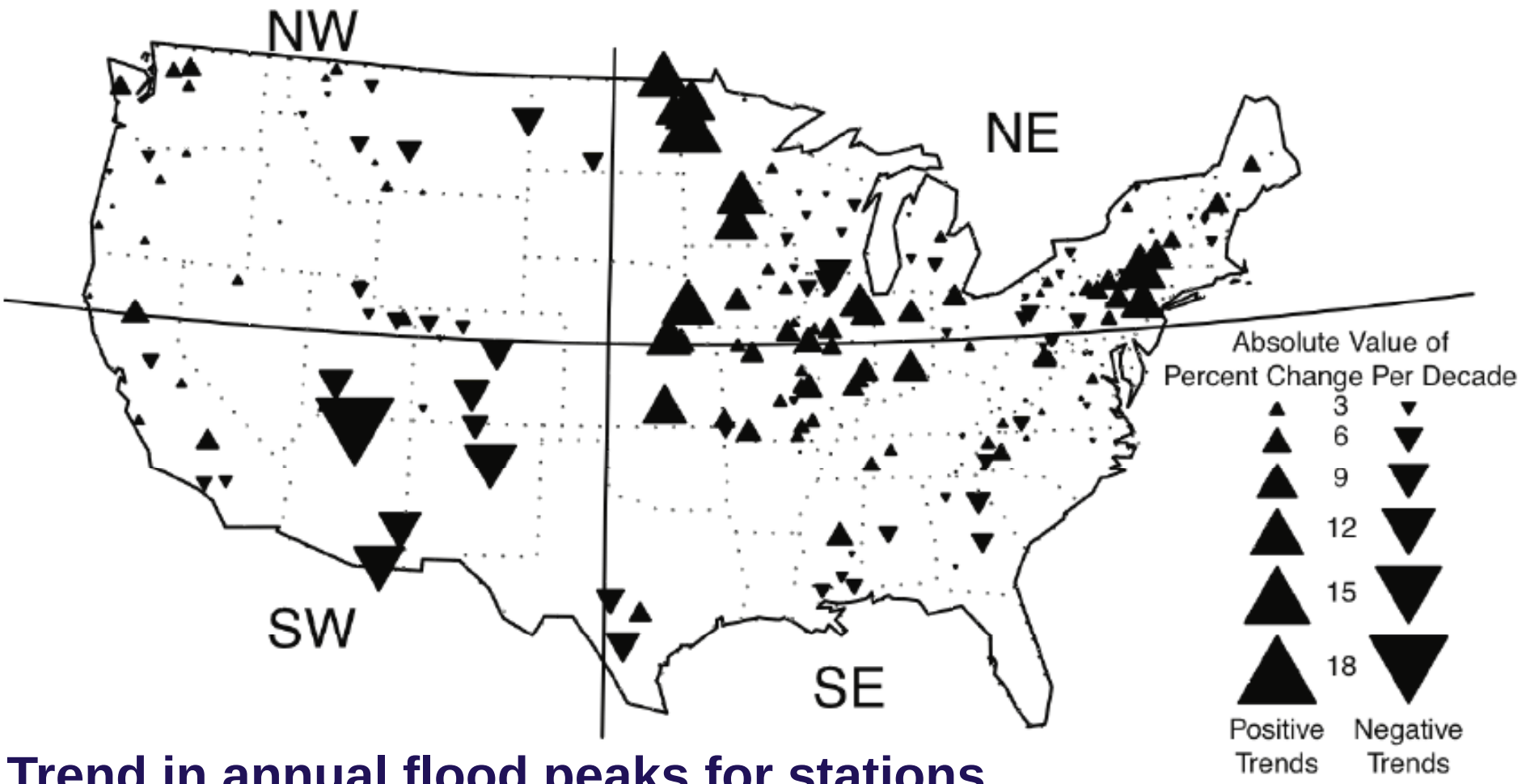
Redistribution of Floods?

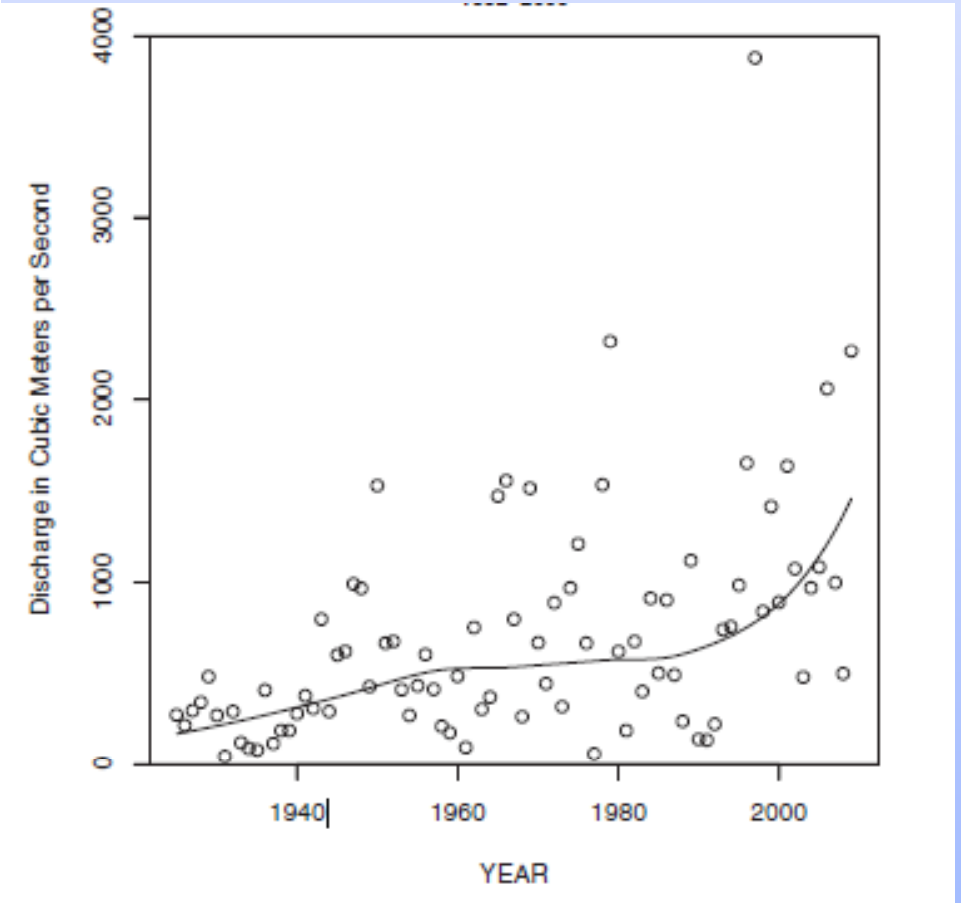


Trend in annual flood peaks for stations having 85 – 127 years of record.

USGS

Hirsch, JAWRA, 2011.

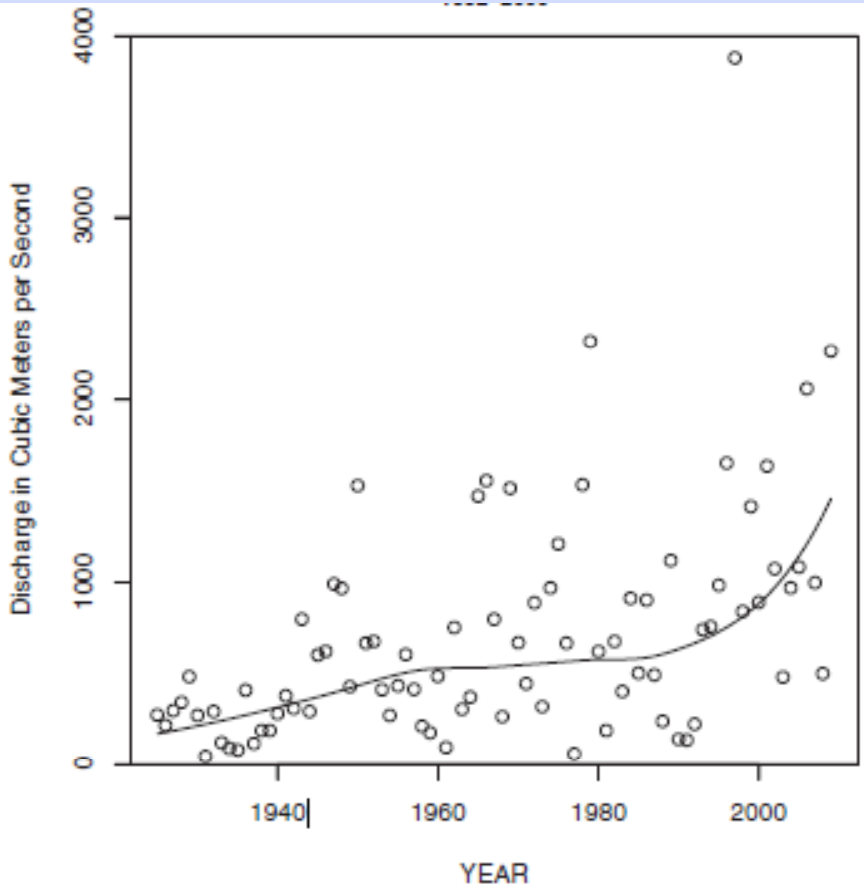
Understanding "Redistribution": Value of Long Record

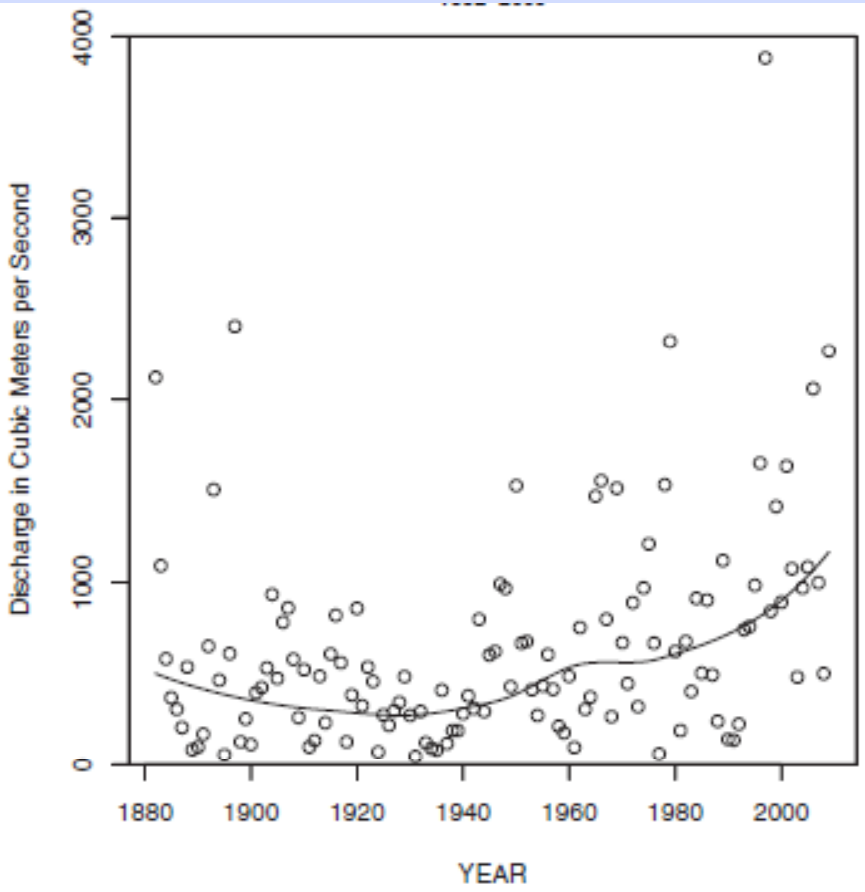


1925 – 2009:
Monotonic Trend

USGS

Understanding "Redistribution": Value of Long Record





1925 – 2009:
Monotonic Trend

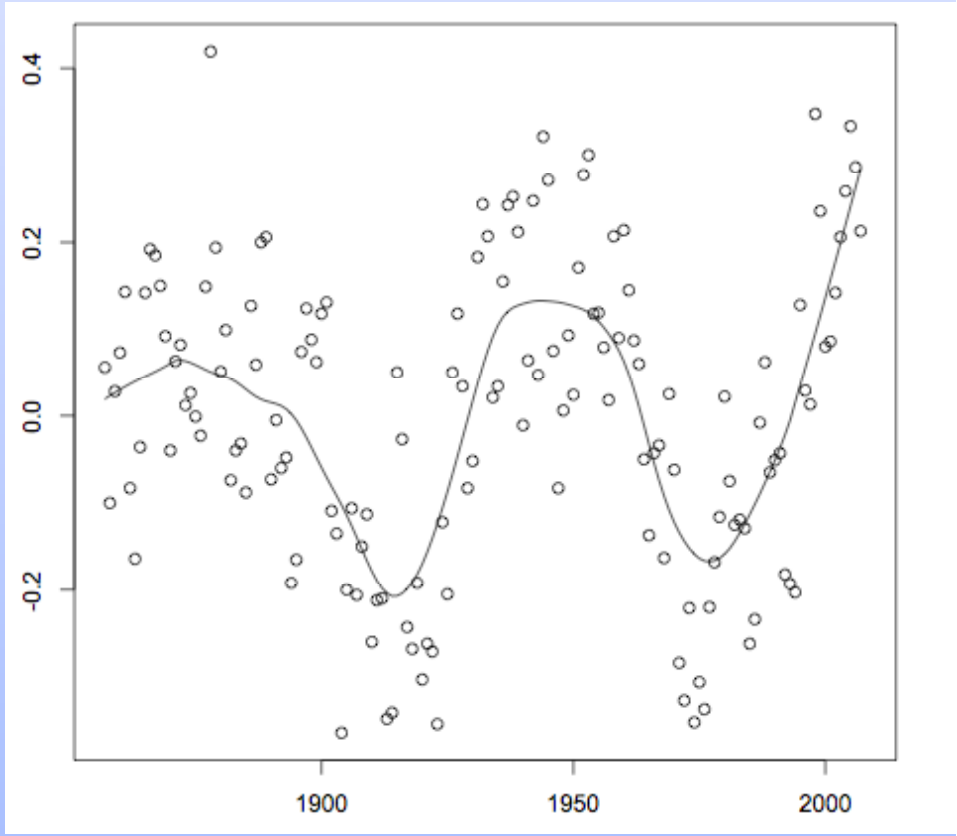
1882 – 2009:
Two-State System

USGS

Hirsch, JAWRA, 2011.

Understanding Variability vs. Change

Pacific Decadal Oscillation



Atlantic Multidecadal Oscillation

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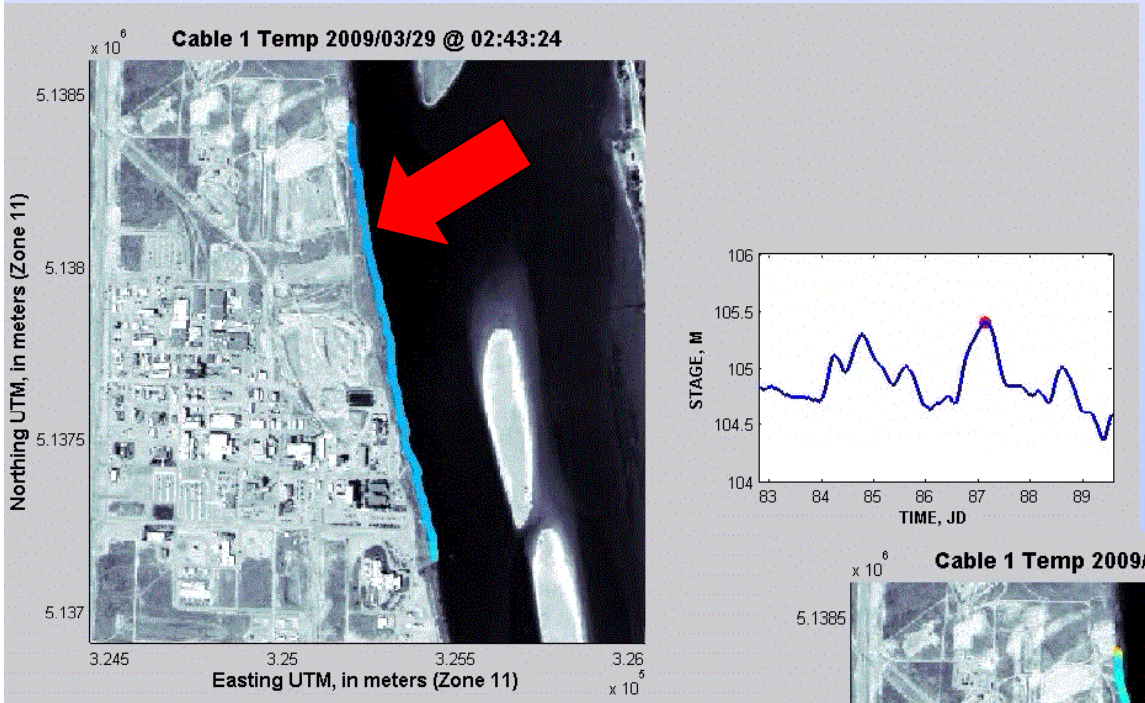
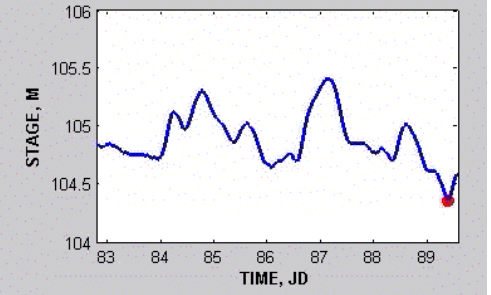
Temporal Variability in GW Discharge





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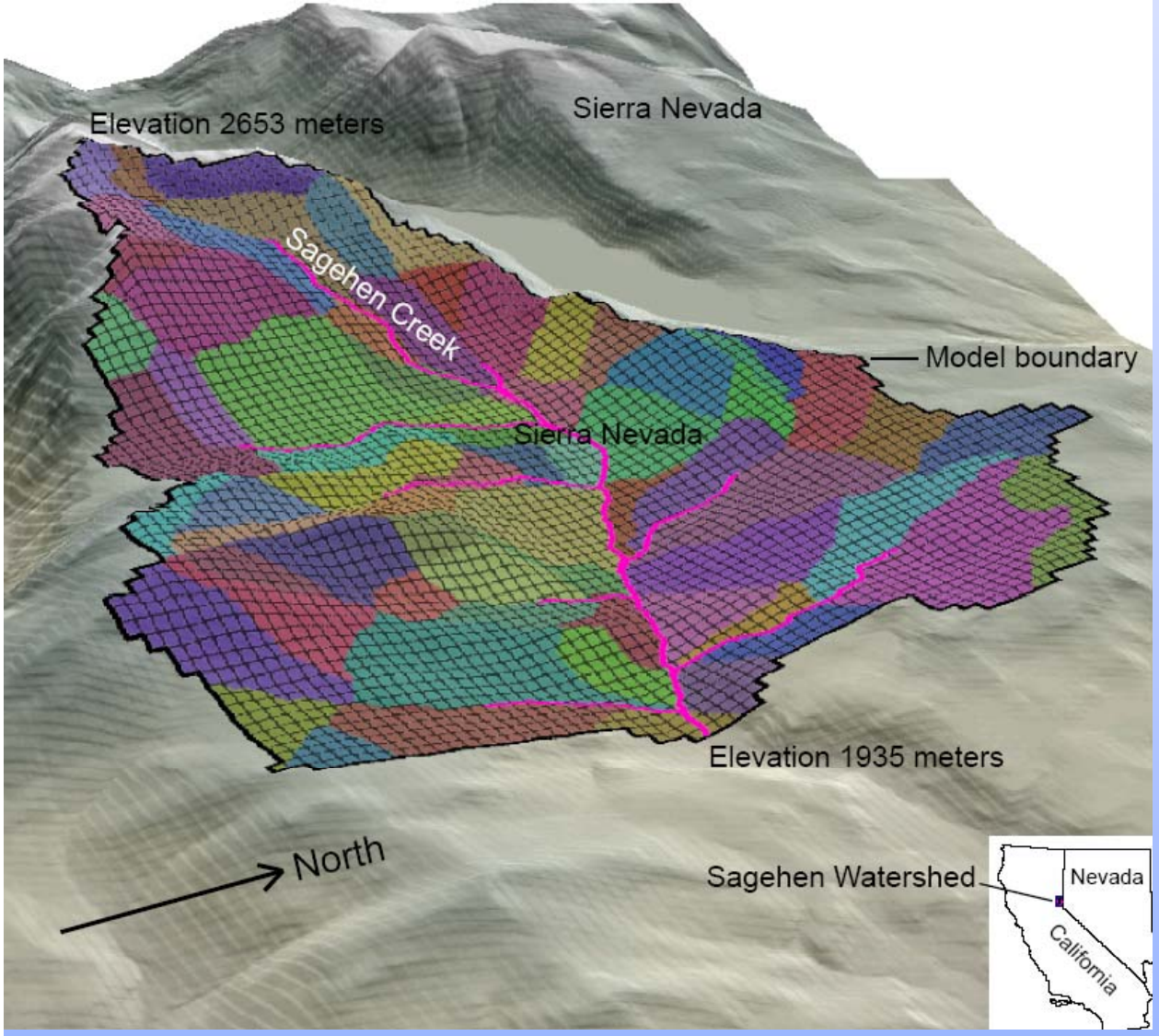
GSFlow for Modeling Coupled GW-SW



PRMS hydrologic response units (colored basins) intersected with ModFlow finite-difference cells.

Enhanced soil-zone dynamics (capillary, gravity-flow, and preferential-flow reservoirs).

Vertical unsaturated-zone flow below soils, streams, and lakes using approx. to Richards' equation.

Model-calculated recharge to water table.

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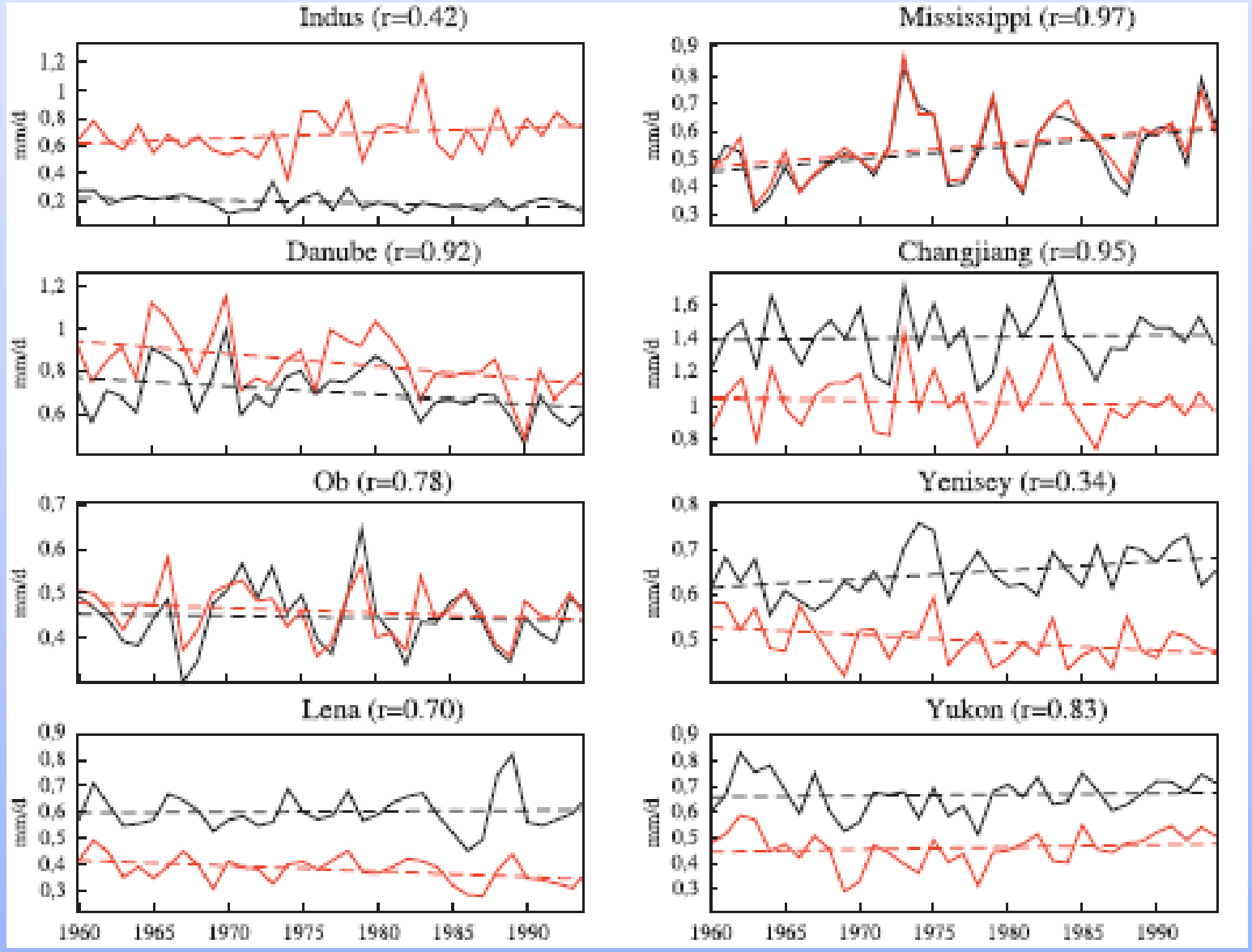
Markstrom, et al., 2008

Model Performance



Simulated (red) and observed (black) annual mean discharges (*Alkama et al., 2011, J. Climate, 24)*

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Model Performance

- **Overall, the modelling of past abrupt events does not give us confidence in the ability of complex models to simulate critical threshold behaviour that we know has occurred in the past. (*Valdes, Nature Geoscience, July 2011)***
- **In all examined cases, GCMs generally reproduce the broad climatic behaviours. . . However, where tested, replacement of the modelled time series with a series of monthly averages (same for all years) resulted in higher efficiency. . . At the annual and the climatic (30-year) scales, GCM interpolated series are irrelevant to reality. GCMs do not reproduce natural over-year fluctuations. (*Koutsoyiannis, et al., 2008, Hyd. Sci. J.)***
- **This implies little skill in precipitation calculated at individual grid points, and thus applications involving downscaling of grid point precipitation to yet even finer-scale resolution has little foundation and relevance to the real Earth system (*Stephens et al., 2010, JGR, 115)***

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Attribution of Change

- **Non-climatic**
  - **Water management**
    - **Reservoirs**
    - **Consumptive use**
    - **GW declines**
  - **Land management**
    - **Tile drains**
    - **Changing land use**
- **Natural variability**
- **New measurement techniques**
- **Greenhouse-driven climate disruption.**

North America during most recent glacial maximum ~20,000 years ago.

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Watershed Modeling for . . .

- **Scientific Understanding**
- **Engineering Design**
- **Hazards**
- **Water-Resources Planning and Management**
  - **Human supply**
  - **Agriculture**
  - **Energy**
  - **Ecosystem needs**
- **Prediction of Contaminant Transport**

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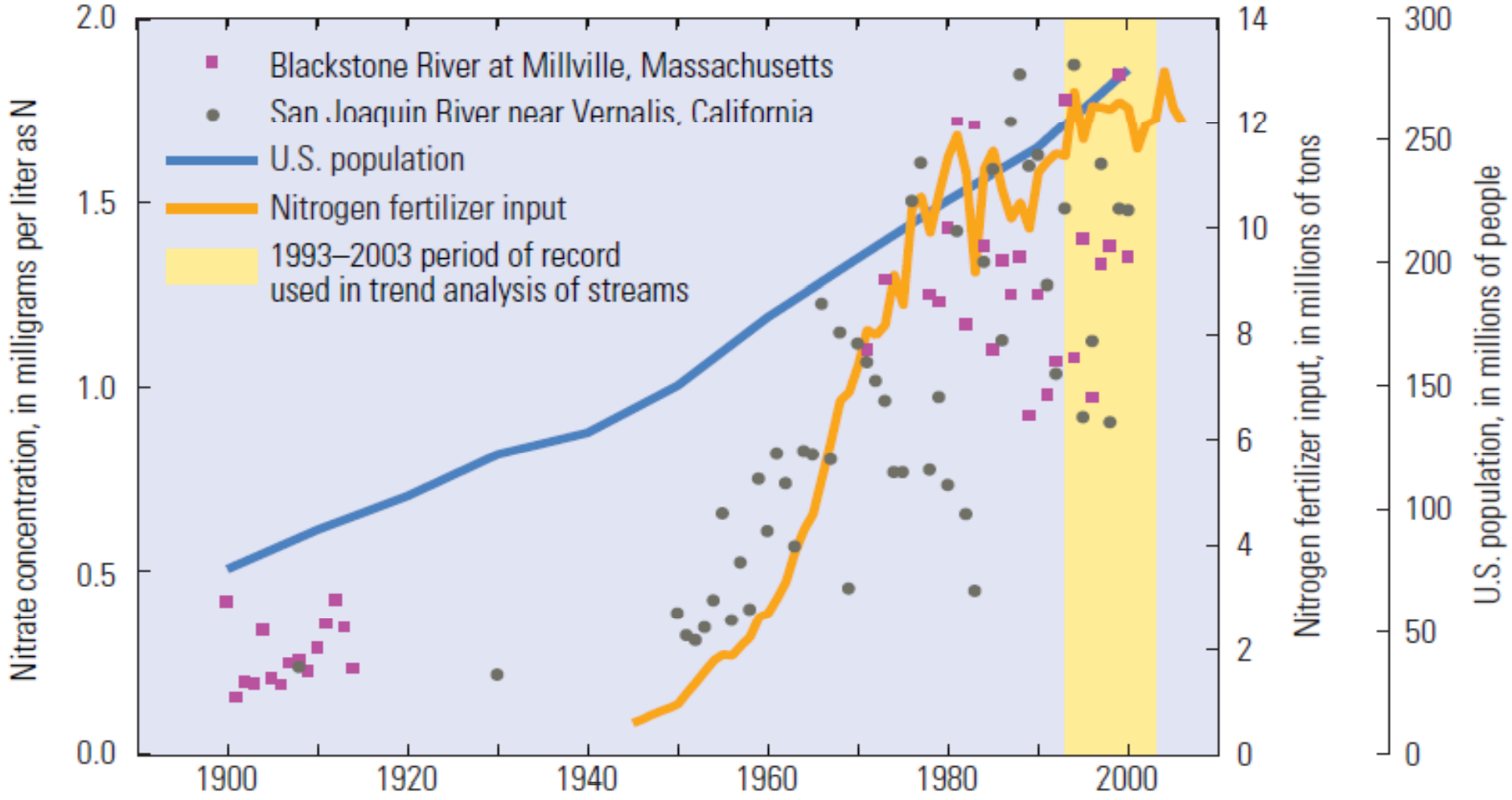
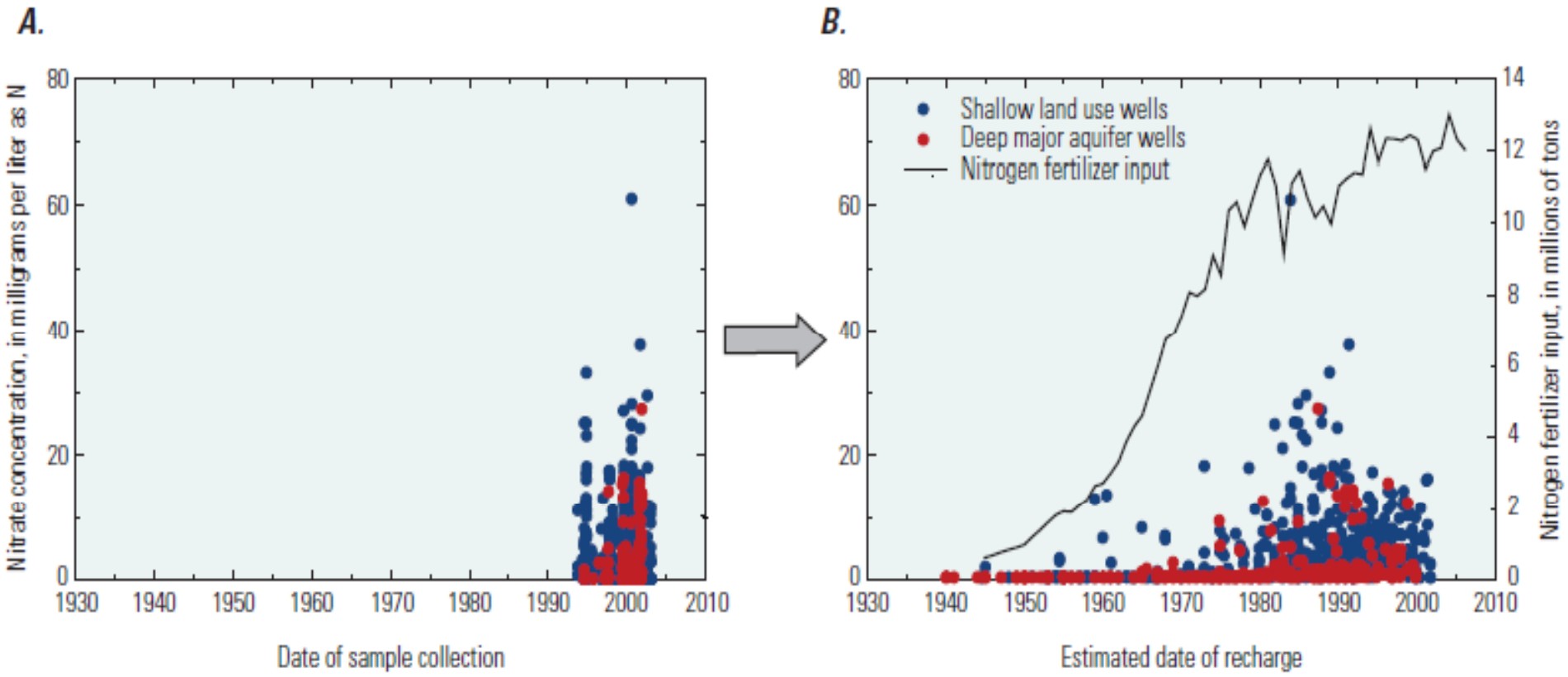
Nitrogen



USGS

Dubrovsky, et al., 2010

Prediction of Reactive Solute Transit



Measured nitrate concentration in shallow groundwater and deep aquifers by (A) date of sample collection and (B) estimated date when the groundwater was recharged

USGS

Dubrovsky, et al., 2010

Water-Cycle Research— Getting the right answer to the relevant questions for the right reason

- ***Observing:*** **Data and data interpretation**
- ***Understanding:*** **Physical processes**
- ***Modeling:*** **Add value to understanding**
- ***Communicating:*** **Ultimate goal**

"There is a lot of practical value in learning how natural systems work."
***Science, 12/15/2006, p. 1697*.**

USGS

Thank you

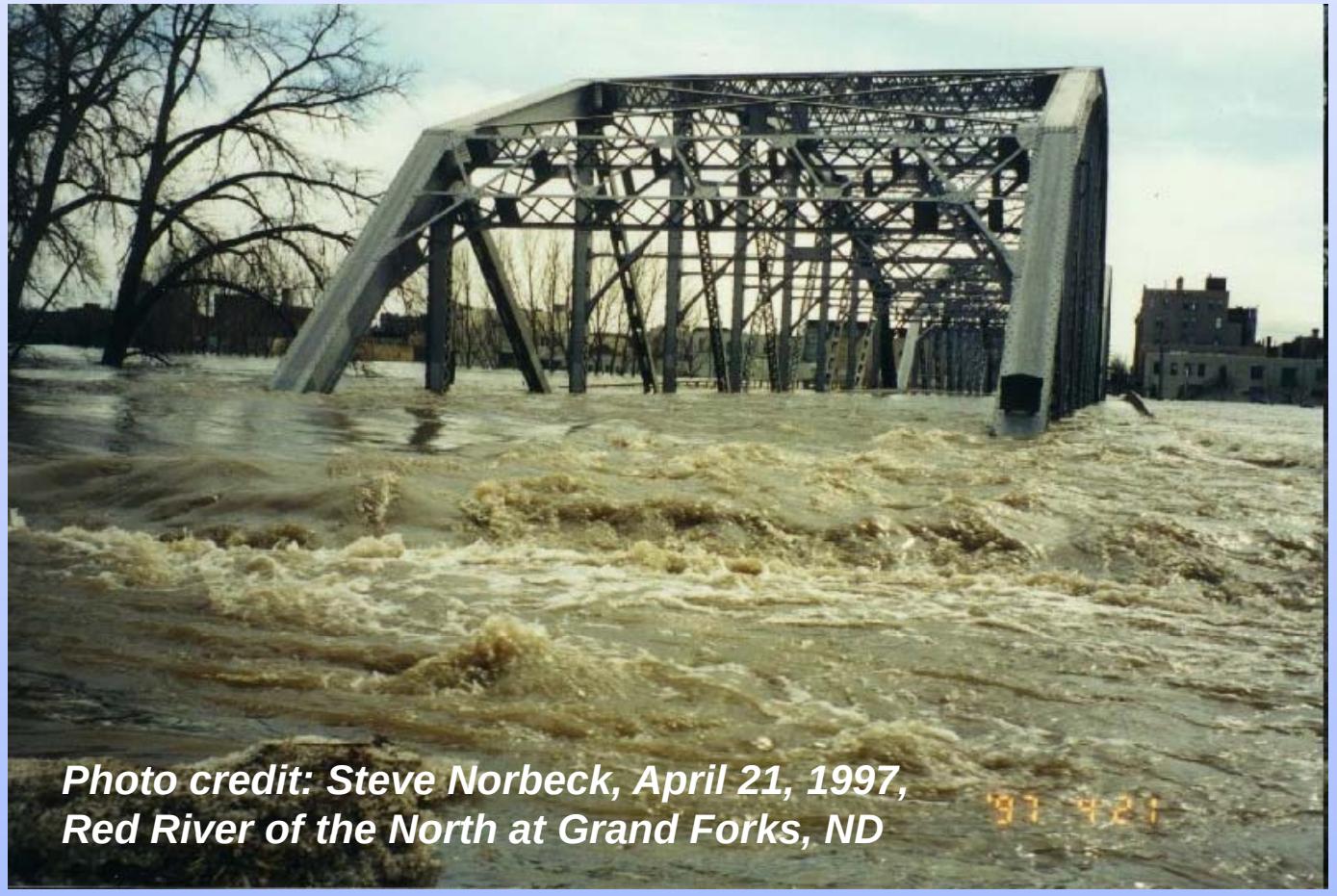


Photo credit: Steve Norbeck, April 21, 1997, Red River of the North at Grand Forks, ND

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